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# BORDEN'S REVIEW *of* NUTRITION RESEARCH

## *MINERAL REVIEW. I.*

BORDEN'S REVIEW
*of*
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# *MINERAL REVIEW. I.*

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In addition to water, which may be classed technically as an inorganic mineral substance, the body contains some fifteen or more inorganic chemical elements almost all of which play specific roles in the functioning of the living cell. These elements, popularly referred to as the minerals, include calcium, phosphorus, sodium, potassium, chlorine, magnesium, manganese, iodine, iron copper, sulfur, zinc, cobalt, bromine and fluorine. Traces of aluminum, arsenic, nickel and other elements have been noted in living tissue, but there is considerable doubt as to their significance. The first seven of these will be discussed in the present Review; the remaining mineral elements, in the following issue.

## *General Functions of the Minerals:*

In addition to possessing specific individual activities in the living organism, the minerals taken collectively, function in three general ways. As summarized by Sherman,* they act:

1. As constituents of the bones and teeth, giving rigidity and relative permanence to the skeletal tissues;
2. As essential elements of the organic compounds which are the chief solid constituents of the soft tissues (muscles, blood cells, etc.);
3. As soluble salts (electrolytes) held in solution in the fluids of the body, giving these fluids their characteristic influence upon the elasticity and irritability of muscle and nerve, supplying the material for the acidity or alkalinity of the digestive juices and other secretions, and yet maintaining the approximate neutrality of the body's fluids as well as their osmotic pressure and solvent power.

## *Water:*

Living matter contains from 70 to 80 per cent water. Most foods, with the exception of fats, contain from 60 to 95 per cent water. In man, over two-thirds of the body weight is due to water. Loss of 10 per cent of the water content of the body results in serious disorders, while a loss of 20 per cent results in death. By contrast, a fasting animal can use up almost the entire supply of body fat and half of its protein before death results. Death results not from an actual deficiency of water *per se,* but from a disturbance

*Sherman, H. C., "Chemistry of Food and Nutrition," Macmillan Company, New York (1941).

in the electrolyte balance (salt concentrations) of the body fluids. Water is needed for the blood, lymph, gastrointestinal secretions (saliva, gastric juice, bile pancreatic and intestinal juices) and intracellular fluid. Water is lost from the body in the urine, saliva, feces, tears, nasal secretions, sexual secretions, milk secretion, vomitings, and by evaporation from the skin and lungs. All the reactions of cellular metabolism take place in a fluid medium. The presence of various mineral salts in solution in the blood, lymph and intracellular fluids is essential for the normal performance of all vital cellular activities.

## *Calcium:*

Calcium is the most abundant mineral element in the body. The body of the average 70 kg. adult (154 lb.) has been estimated to contain about 1200 grams of calcium. The calcium of the body is concentrated chiefly in the bones (about 99 per cent) which constitute the normal storage points for this element. It is stored in the form of calcium phosphate and calcium carbonate, the proportion commonly being three molecules of tricalcium phosphate to one of calcium carbonate. Smaller amounts of calcium are found in the skin, teeth and blood serum.

**Metabolism:** Calcium is absorbed in the small intestine. Factors which increase the solubility of calcium salts likewise promote the degree of absorption and utilization of this element. An acid medium increases the solubility and absorption of calcium. Excess fat, phosphate, oxalate or phytate reduce calcium absorption because of the formation of insoluble calcium salts. Vitamins C and D facilitate the utilization of calcium, but the mechanisms involved are not clearly established. The milk sugar, lactose, increases lactic acid fermentation in the intestine, thereby producing an acid medium favorable to the absorption of calcium.

Excess calcium in the blood resulting from abnormal activity of the parathyroid glands causes hardening of various organs (heart, lungs, arteries, kidneys, spleen, skin, eyes) due to calcium deposition and a sustained contraction of the heart muscle known as "calcium rigor." The excess calcium is derived from the bones which inevitably become softened and weakened.

**Functions:** A primary function of calcium is to build bone and teeth. It is also an important factor in maintaining a proper osmotic balance in the blood and tissues. Calcium ions are essential for the transformation of chemical energy into muscular contractions, for the regulation of the heart beat, and for the normal functioning of the blood coagulation process. Calcium ions function in the activation of certain enzymes and appear to be essential for lactation.

**Deficiencies:** There are relatively large, easily mobilized stores of calcium in the bones. Consequently an acute calcium deficiency rarely develops in adults unless other metabolic disturbances are present as well. These include phosphorus deficiency, vitamin D deficiency and disturbances in the functioning of the parathyroid glands which regulate calcium metabolism.

In infantile rickets, which is precipitated by a deficiency of vitamin D, there is an appreciable loss of calcium (and phosphorus) from the bone and failure to deposit and retain sufficient calcium in newly growing bone. A dietary insufficiency of calcium may also be a predisposing factor in rickets, since in children there are as yet no appreciable stores of calcium in the bones. Any substance which prevents the adequate retention of calcium and phosphorus will also lead to rickets. Excesses of other metals (beryllium, magnesium, iron, lead and tellurium) which form insoluble phosphates have been reported to result in rickets. In osteomalacia, the adult counterpart of rickets, there is softening of the bones due to loss of calcium. The predisposing causes, however, are thought to be endocrine factors rather than simply dietary deficiency of calcium, particularly since the disorder is much more common in the female than in the male. In adults the blood level of calcium, the teeth and supporting portions of the bones are preserved at the expense of the reserve supply in the spongy part of bone. The popular belief that the dental caries so prevalent in pregnant women is due to withdrawal of calcium from the teeth by the fetus is erroneous. Calcium stores are withdrawn from the bones, not from the teeth, but again—as in osteomalacia—other metabolic factors, probably of endocrine origin, are responsible for the development of caries during pregnancy.

Renal rickets is a disease of childhood in which chronic kidney disease causes bone changes resembling severe rickets. The bone changes are caused by a deficiency of calcium and phosphorus in the blood, resulting from an abnormal excretion of phosphorus into the intestinal tract. Vitamin D is ineffective in this disorder.

Lowered levels of calcium in the blood due to rickets, parathyroid deficiency or other cause, result in a condition known as tetany. It is characterized by severe muscular spasms which lead to death from asphyxia unless checked by injection of calcium salts or parathyroid extract.

**Requirements:** The adult requirement for calcium has been estimated to be about 0.8 gram per day, or about one gram of calcium for every 100 grams of protein. Not all of the calcium in foods is available to the body, some occurring as insoluble salts which cannot be absorbed from the gastrointestinal tract. The ratio of calcium to phosphorus in the diet is another

important factor in calcium availability. Excessive phosphorus in the diet forms insoluble salts with calcium, thereby creating a deficiency of utilizable calcium. The calcium phosphorus ratio should be about 1 to 1.5 or 1 to 2. Children, adolescents, pregnant and lactating women have increased need for calcium and require from 1.0 to 1.5 grams per day.

**Sources:** Dairy products are the best sources of calcium both with respect to quantity and availability. Also, the calcium and phosphorus of milk are present in the ideal ratio. One quart of milk per day provides the optimum amount of calcium for growing children. Six glasses per day supply the needs for pregnancy and lactation. Other good food sources of calcium are: Cheese, nuts, ice cream, molasses, kale, green beans, peas, dried beans, fortified baby cereals, clams, shrimp, sardines, cabbage, broccoli, wheat, soy flour, maple syrup, oranges. Calcium is available for therapeutic purposes as calcium lactate, gluconate or chloride.

## *Phosphorus:*

Phosphorus is an essential constituent of every living cell. It is present in the body in numerous forms as a component of organic substances (phosphoproteins, phospholipids, enzymes) and as inorganic mineral salts in blood, muscle and other tissues. From 70-80 per cent of the body phosphorus is in the skeleton, 10 per cent is in the muscles and 1 per cent in the nervous system. Phosphorus is widely distributed in foods so that there is not much concern in planning diets to insure adequate amount of this element. Phosphorus deficiency occurs more frequently in cattle than in other species.

**Functions:** The compounds of phosphorus have more functions in the living organism than probably any other single nutrient. There are at least fourteen vital functions of phosphorus compounds involving muscle metabolism, intermediary carbohydrate, fat and protein metabolism, brain and nerve metabolism. Phosphorus compounds play a significant role in the chemistry of the blood, in skeletal growth, in tooth development, in regulating the acid-base balance of the body and in vitamin and enzyme activity. The dynamic nature of bone and tooth structure, as well as of other phosphorus-containing tissues, has been demonstrated through the use of radioactive phosphorus. The functions of phosphorus compounds are so numerous and their intermediary metabolism so complex that they cannot be further detailed within the limits of this Review.

**Deficiency:** Because of the rich stores in the bones and the ample supply in foods, phosphorus deficiency in humans is a rare phenomenon. It may be fairly common in cattle. In dairy cows a deficiency causes failure and

depravement of appetite, stiffness and muscular weakness and marked loss of weight. Good recovery is noted when phosphorus is added to the diet. Cattle may develop an intense craving for phosphorus which manifests itself in bone eating, particularly in regions where the soil is deficient in this element.

The role of phosphorus in rickets is closely associated with that of calcium. Studies with radioactive phosphorus have demonstrated several interesting facts concerning the metabolism in rachitic rats, but thus far have offered no explanation for the basic function of phosphorus in bone metabolism. Recent studies on the phytin phosphorus of cereals (inositol-hexaphosphoric acid) reveal that this poorly utilized source of phosphorus may be improved with higher levels of vitamin D intake. Excess intake of phytic phosphorus is thought to be a significant factor in the development of rickets.

**Requirements:** The adult requirement is about 0.9 gram of phosphorus per day, increasing to 1.5 grams during pregnancy and lactation. Growing children require about 1.3 grams per day.

**Sources:** As with calcium, dairy products are the best sources of phosphorus in our type of dietary. One quart of milk a day provides the recommended adult requirement and a major portion of the child's requirements. In addition to milk, good sources of phosphorus are cheese, eggs, fish, lean meat, wheat, oatmeal, nuts, dried beans, corn, fortified baby cereals. In the Orient, the Arctic, Africa, certain parts of Asia and South America where dairy products are not available the calcium and phosphorus supply is obtained from sea foods, and through the use of fish and animal bones in cookery, green leaf foods and other plants which do not occur in our regions.

### *Sodium, Potassium and Chlorine:*

Practically all of the chlorine involved in metabolism is in the form of chloride ions, in which form it is also ingested and excreted. The chlorides are chiefly those of sodium (common salt) and potassium. Sodium salts (sodium chloride and sodium bicarbonate) occur chiefly in the blood plasma and other extracellular body fluids. Potassium salts (potassium chloride, phosphates and bicarbonates) occur largely within the cells—in the blood corpuscles, in muscle protoplasm and in other tissues and in certain secretions, particularly milk. Sodium, potassium and chlorine are intercombined in various compounds, so that a discussion of their functions involves them collectively as one or more groups.

**Sodium Chloride:** Sodium chloride has two vital functions: (1) It helps maintain the acid-base balance of the body and (2) it is largely responsible

for the total osmotic pressure of the extracellular fluids. It also stimulates the flow of digestive juices. Actual intake of salt in normal individuals varies from 2 to 30 grams per day depending upon taste. Abnormally high intakes of salt (over one ounce per day) disturb the water balance of the body resulting in a swelling of the tissues known as edema. Excess sodium or chloride is readily excreted by the kidneys; other pathways of salt excretion are through the feces and through the skin in sweat. Extreme sweating during exertion and high temperature causes so great a loss of sodium chloride from the blood as to precipitate severe leg and abdominal cramps. To prevent these effects extra salt may be added to the food or drinking water. During salt deprivation, the kidneys adjust the excretion of salt to a minimum level to retain normal body stores. Likewise, it has been reported that a similar adjustment is made both in salt concentration and volume of sweat in acclimatization to the tropics, unless, of course, hard physical labor is involved.

Additional salt and water intake is indicated in prolonged vomiting (chloride loss), diarrhea (sodium loss), adrenal cortex insufficiency (derangement of salt metabolism causing decrease of sodium in blood plasma and a corresponding increase of potassium), and shock resulting from loss of blood volume in surgery, wounds or severe burns.

Certain estrogenic hormones stimulate retention of sodium, chloride and water. This is frequently manifested by temporary premenstrual gain in weight due to salt and water retention and to edema which is a common complication of pregnancy. Restricted salt intakes help reduce the edema of pregnancy and have also been reported to be effective in relieving headaches associated with premenstrual tension.

For a number of years it has been known that a diet of low salt content is helpful in treating hypertension, and recent investigators have reported that congestive heart failure conditions are due to the inability of patients to eliminate sodium as readily as normal patients. In these cases low salt diets should contain less than 0.5 gm. of sodium per day. The dietary problem is to supply enough protein without using milk or other materials with normal sodium content. One proposed solution is to use dialyzed milk, which contains little or no sodium.

**Potassium:** Potassium has been related to a great number of functions but the details of the mechanisms are poorly understood. It is present in all the cells of every tissue, but only a small amount occurs in the body fluids. Potassium is necessary for growth; it is important in carbohydrate metabolism. Potassium is involved in nerve and muscle excitability and in

transmission of nerve impulses. Blood potassium levels are elevated in Addison's disease (adrenal cortex insufficiency) and in diabetes mellitus. Blood potassium levels drop sharply in the rare disease known as periodic muscular paralysis, indicating that the loss of muscle function is probably due to a concomitant increase in intracellular potassium. Recently potassium chloride has been reported to induce favorable responses in certain allergic conditions, thereby presenting a new hypothesis that allergy may result from a faulty metabolism of mineral salts.

**Requirements:** Among the animals, the herbivora require salt in the diet while the carnivora do not, the latter obtaining sufficient salt from the flesh and, more especially, the blood of their prey. In man, the craving for salt in quantities greater than those occurring naturally in food, is an unexplained appetite shared with the herbivorous animals. Natural foods contain sufficient sodium and potassium salts to prevent the occurrence of any deficiency of these minerals in the absence of complicating pathologies.

**Sources:** Potassium occurs in all vegetables and meats. Sodium chloride occurs naturally in meats and is usually added in the preparation and serving of most vegetables. The various salts of organic acids in vegetables and fruits are an additional source of sodium. These compounds are oxidized during metabolism, leaving a residue of sodium bicarbonate, the "alkaline reserve" of body fluids.

### *Magnesium:*

Magnesium has been demonstrated to be a nutritional essential, but the nature of its metabolic role remains obscure.

**Metabolism:** In some respects magnesium metabolism parallels that of calcium metabolism. Like calcium, magnesium is stored (about 70 per cent) in the bones. There is about 100 to 200 times as much calcium in the bones as there is magnesium. The concentration of calcium in the plasma is about four times greater than that of magnesium. In the cells, however, magnesium is present in far greater concentration than is calcium. The absorption of magnesium from the intestinal tract resembles that of calcium. Excessively high intakes of fats, calcium and alkalies retard the absorption of magnesium. The retention of magnesium is proportional to the immediate need of the body. Infants and children have relatively large retentions of magnesium; it is necessary to maintain the normal structure of growing new tissue. The magnesium content of the blood serum is decreased in rickets and during menstruation and pregnancy. Magnesium and calcium usually exhibit antagonistic effects.

Recent work has shown that magnesium excretion, unlike its absorption, does not parallel calcium elimination. In exophthalmic goiter, for example, it has been found that magnesium may be stored in spite of a serious calcium loss. No condition of excessive magnesium excretion in man has yet been reported.

**Deficiency:** In experimental animals on a magnesium-low diet, a number of symptoms have been observed. These appear to be divided into two distinct phases. The first of these is a dilatation of the blood vessels due to an increase in blood volume and a peculiar state of overexcitability. These symptoms are followed by the second phase which is characterized by nutritional failure, severe kidney damage, cessation of growth and ultimate death. Other symptoms of malnutrition are common and include general loss of hair, rough, ill-kempt and sticky coat, diarrhea and edema.

The hyperirritability observed in the first phase of magnesium deficiency represents a special form of tetany distinguished by a normal blood level of calcium and a marked reduction in the blood plasma level of magnesium. In animals, a pronounced protrusion of the eyeballs frequently appears several days before the onset of a convulsion. This is considered a symptom of combined calcium and magnesium deficiency. The kidney changes in magnesium-deficient animals are believed to be associated with the abnormal increase in the calcium content of these organs which invariably accompanies magnesium deprivation. Because of the vasodilatation effect of early magnesium deficiency in experimental animals, there is some speculation as to a possible role of this factor in the development and control of high blood pressure in man.

**Requirements:** There are no specific known quantitative requirements for magnesium. The average intake of magnesium in the United States is 0.27 gram per day, which appears to be sufficient.

**Sources:** The chief source of magnesium in the average diet is vegetables. It occurs principally in the green coloring matter or chlorophyll. Some magnesium also occurs in whole grains. There is usually no likelihood of a dietary insufficiency of magnesium, although diets consisting chiefly of refined cereals and milk (as for pre-school children) may contain less than desirable amounts of magnesium. Good food sources include: Wheat germ, honey, endive, kohlrabi, fresh figs, chocolate, nuts and dried peas and beans.

### *Manganese:*

Manganese is found in all human tissues, in animals and, to a greater extent, in plant tissues. The absence of manganese in plants causes cessation

of growth in simple plants and loss of green color in more complex plants. In the animal body, manganese is stored in the liver, pancreas, lymph nodes and kidneys.

**Functions:** Early experimental studies with laboratory animals demonstrated that the addition of minute traces of manganese to normal adequate diets improved the appearance of the animals, increased their activity and stimulated more rapid growth in the offspring. With the development of highly synthetic, purified diets it later became possible to examine the effects of actual manganese deficiency on test animals. It was soon found that manganese-deficient male rats became sterile and exhibited degeneration of the reproductive organs. Female rats on a manganese-deficient diet produced young which failed to live and, in addition, refused to suckle either their own young or normal young from the stock colony. In addition to disturbances of the reproductive function, growth failure was found to be an additional manifestation of manganese deficiency.

The manganese requirements of fowl, particularly of the chicken, are much higher than those of any mammal studied. For this reason, adequacy of manganese intake is of practical importance in poultry nutrition. One of the most outstanding manifestations of manganese deficiency in the chick is the condition known as perosis or "slipped tendon," an anatomical deformity of the leg bones. Manganese is also essential for the normal bone development of the embryonic chick and for the maintenance of normal hatchability of eggs.

It has been demonstrated *in vitro* that manganese is involved in the activation of a number of important enzyme systems (phosphatases, arginase, cozymase, carboxylase, cholinesterase) and considerable evidence exists that similar activation occurs within the human body as well. Balance studies on manganese retention in pre-school children have provided presumptive evidence that this element is essential to the physiological development of children.

Experiments on the toxicity of large doses of thiamine in rats on low manganese diets have led to the conclusion that a metabolic relation exists between the two substances. It has been postulated that manganese is essential in the utilization of thiamine in the tissues, probably functioning as a vital catalyst in the oxidative processes in which the vitamin is involved.

**Requirements:** Suggested manganese requirements have been set for the prevention of perosis in the chick—about 35 to 40 parts per million of manganese in the ration. The amount varies with the breed of chick. It must also be taken into account that other factors exist which influence perosis,

namely the calcium and phosphorus content of the diet and the members of the so-called "anti-perosis complex" which includes, besides manganese, choline and related compounds, biotin and an unidentified nutrient found in aqueous liver extract.

The indispensability of manganese in the human diet has not yet been established, consequently it is not possible to set a quantitative requirement for this element in the adult. From observations on manganese balance studies in young children it is suggested that the diet of such children should probably provide from 0.02 to 0.03 mg. of manganese per kilogram (2.2 lbs.) of body weight.

**Sources:** Cereals and plant foods, meat, poultry, dairy products and fish are the best sources, in the order given. Wheat bran and blueberries have been found to be exceptionally high in manganese.

# *NEWS DIGEST*

**ICE CREAM FLAVORS**—Making a universally popular food even more so through improvement in flavors has been an important wartime activity of the ice cream industry. The increasing availability of frozen fruits has proved a great aid in this respect. Research and experience have demonstrated that the use of frozen fruits produces superior flavors, whereas heating fresh fruits tends to destroy some of the flavor. Fruit purees, or sometimes syrup, have been used to produce multi-flavored ice creams, the flavoring being injected in a stream into the semi-frozen ice cream. The use of more chocolate liquors has resulted in an improvement in the flavor of chocolate ice cream. A special section for the preparation of fruits and syrups is a new innovation in almost all ice cream plants which is expected to add considerably to the production of new and more delightful flavors in ice cream products. *Ice Cream Trade Jr. 42,* 40 (1946).

**FROZEN CITRUS JUICES**—Newest members of the frozen food family are frozen citrus concentrates which, when reconstituted by the addition of water, possess the natural flavor and nutritive value of the corresponding fresh juice. Government tests have shown the reconstituted juices to contain amounts of vitamin C, of minerals and of natural fruit sugars equivalent to the fresh juice. Depending on the strength of the particular concentrate, from 3 to 9 parts of water are added to reconstitute the original juice. *Jour. Am. Diet. Assoc. 22,* 654 (1946).

**STARVATION AND REHABILITATION** — Thirty-two human subjects, volunteers in a year-long experiment, have provided new insight into the problems of starvation, its consequences and the response to subsequent nutritional therapy. It has been estimated that 80 per cent of the world population suffers from some degree of undernutrition; many millions are existing in a state of semi-starvation or have not yet recovered from recent semi-starvation. Accurate scientific knowledge concerning the effects of malnutrition in war-ravaged countries was desperately needed. To this end, an experiment was planned to determine physiological, psychological and performance characteristics of a group of normal men, first on an adequate diet and then on a European famine diet designed to cause loss of one-fourth the body weight in six months. Following this, the men were rehabilitated on different controlled relief diets so as to estimate the effects of different caloric, vitamin and protein levels on the character and rate of recovery. The semi-starvation diet consisted mainly of potatoes, turnips and coarse cereals; meat, fish, cheese and eggs combined totalled only about one ounce a day. The diet provided 1,760 calories (normal requirement of subjects about 3,150), 49 grams of protein and fair amounts of vitamins and minerals, The subjects exhibited progressive and severe weakness, depression, fatigue, anemia, bradycardia and edema. There were slight disturbances in coordination, speed of reactions, and amount of plasma proteins. Vision, hearing and intelligence remained unimpaired. Vitamin deficiency signs were not obvious. In rehabilitation it was found that only diets averaging over 2,500 calories daily allowed significant recovery and with the best diet, averaging about 3,500 calories, recovery was only about 50 per cent in 3 months. Full recovery required 8 to 12 months. Extra vitamins and proteins had little apparent effect on the rate or course of recovery.

**Report of a Participant** — The following excerpts from a talk by a participant in the experiment just described give a vivid subjective description of the signi-

ficance of starvation, even under conditions recognized as merely temporary.

"In November, 1944, I went out to Minnesota to take part in a nutrition experiment. Actually it was an attempt to determine the minimum basis on which large populations can be brought back from a starving situation. . . .

"We did get every kind of psychological test it is possible to devise. In these tests we were asked what seemed to be stupid questions, personal inventories, intelligence tests and power tests to determine our mental ability. We had all of them and took them over and over again. They probably were fairly valuable. One of the increasingly important aspects of starvation, we found, was the psychological outlook when we were normal and when we weren't. This produced some extremely interesting results. . . .

"The psychological aspects of starvation are unbelievable. We joined in the experiment because we were concerned about people abroad and wanted to do what we could to help those less fortunate than ourselves. I think we lost that feeling after about two months. At the end of five months of starvation we no longer cared about the people abroad. The prevailing thought was: "I am hungry." That was all that was important. The only important thing left was whether I was ever going to get food. I was only interested in myself.

"We had to keep answering questions and our whole attitude was introspective. We lost our semblance to humanity and became similar to beasts. I remember seeing a man on a corner in Minneapolis and I got mad at him because he could go and have something to eat. A couple of days later I saw a kid on a bicycle. My first thought was 'how could anybody get that much energy.' Then I thought 'he is probably going home to supper. I hate him.' That is one of the most awful things I know.

"When the war ended we were on the way back—on the first month of rehabilitation. We were sitting at the supper when the news came. The end of the war meant a lot to us of course. We talked about it for as long as 20 seconds and then discussion was about what we were going to eat tomorrow. News like that which was so important meant a lot to us, and to think that for only 20 seconds we talked about it and that was all.

"What does it all mean?

"It comes to this. If you are going to bring people back you must send them tremendous amounts of food. Quality of food is not as important as quantity." *Jour. Am. Diet. Assoc. 22,* 587 (1946).